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MEASUREMENT OF SAFETY LEAD HEAT LEAK

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The present protection scheme[1] for the Energy Doubler is based on one safety lead per bending magnet for dumping the magnet energy in the event of a quench. Although the safety leads are designed to carry no electric current during normal operation, they present a source of heat that has to be taken into account in the specification of the refrigeration system. In this memo we report measurements made on the present model of one such lead.

Figure 1 presents a simplified drawing of the model tested. It is a gas cooled lead which doubles as a pressure relief pipe. Two gravity action check valves control the flow of the gas: the lower one prevents pressure oscillations and the upper one keeps the normal condition cooling gas flowing through the annular path for better heat exchange with the current carrying nickel pipe.

In the test setup the low temperature feedthrough was not used and the lead was soldered to one end of a specially designed copper piece, the other end of which was immersed in liquid helium. This copper piece has in it a 1.905 cm diameter, 18.10 cm long solid cylindrical body, R, thermal guarded by a copper tube attached to the lower part of the piece. Two carbon thermometers, T_2 and T_1, measure the temperature drop across R caused by the heat current, $\dot{Q}_1$, from the safety lead to the helium bath.

Figure 2 shows the test setup. The end of the copper piece that is soldered to the lead is provided with an electric heater, H1, and a

52 cm long, .79 mm i.d., .102 mm wall, stainless steel capillary which brings liquid helium from the bath to the lead. A set of cuts between the lead and the cylindrical body allow for some flexibility on this otherwise rigid heat path. The capillary, even when filled with stationary 'iquid, conducts a negligible part of the heat to the bath.

The thermal circuit can be therefore indicated by Fig. 3. Four relevant heat currents are indicated: $\dot{Q}_1$ - the heat flowing from the environment and room temperature walls into the lead; $\dot{Q}_2$ - the calibrated heat introduced by means of the electric heater H1; $\dot{Q}_3$ - the heat current that the lead delivers to the liquid helium bath (through the copper cylinder R); and $\dot{Q}_4$ - the heat current transferred to the helium gas flow. Of these only $\dot{Q}_1$ is not measured. $\dot{Q}_2$ is the simplest to measure and control using a 4-lead technique and regulated electric current supply. $\dot{Q}_3$ is obtained from the temperature drop T_1-T_2 across the cylinder R, which was calibrated using $\dot{Q}_2$ without the safety lead. $\dot{Q}_4$ is calculated by measuring the mass flow rate, $\dot{m}$, the temperature of the gas flowing out of the lead, T_t, and finding[2] the enthalpy increase from the liquid state and therefore $\dot{Q}_4$ is the power absorbed by the flowing helium in a steady state condition.

The mass flow rate m was adjusted by a control valve after the gas was warmed up and measured by means of a wet test meter and a clock under known pressure and temperature near room values. The temperature, T_t, was measured with a thermistor immersed in the gas flow at the top of the safety lead.

Table I presents the results of the calibration runs for R. On this calibration the temperatures T_1 and T_2 are used only as parameters to compare $\dot{Q}_2$ with $\dot{Q}_3$ and do not have to be traceable to standards. Therefore, we used carbon resistors whose calibrations had to be checked. Hence, the reason for another electrical heater H2 and a small correction to the calibration curve. This calibration transfer of $\dot{Q}_2$ to $\dot{Q}_3$ could have been done in a direct way using the actual resistance values instead of temperatures but some physical insight on the experiment would be lost.

The results of the final runs are presented in Table II. Several runs were needed to debug the system, get all relevant variables controlled and become familiar with the equilibrium time constants. Several points with non-zero values of $\dot{Q}_2$ were included, they reflect a correct performance for the measuring method involved which is a rather uncommon one. These points also give an idea of the scattering in the results.

The main result, mass flow rate as a function of heat load, is plotted in Fig. 4. The rule of thumb for overall refrigeration economy (3W vs 1ℓ/hr) plotted as a load line indicates that the flow rate should be adjusted to 7.5 mg/sec.

REFERENCES

[1]R.H.Flora and D.F.Sutter; Trans. IEEE, NS-22, 1160 (1975).

[2]R.D.McCarty, Thermophysical Properties of Helium-4, NBS Technical Note 631.

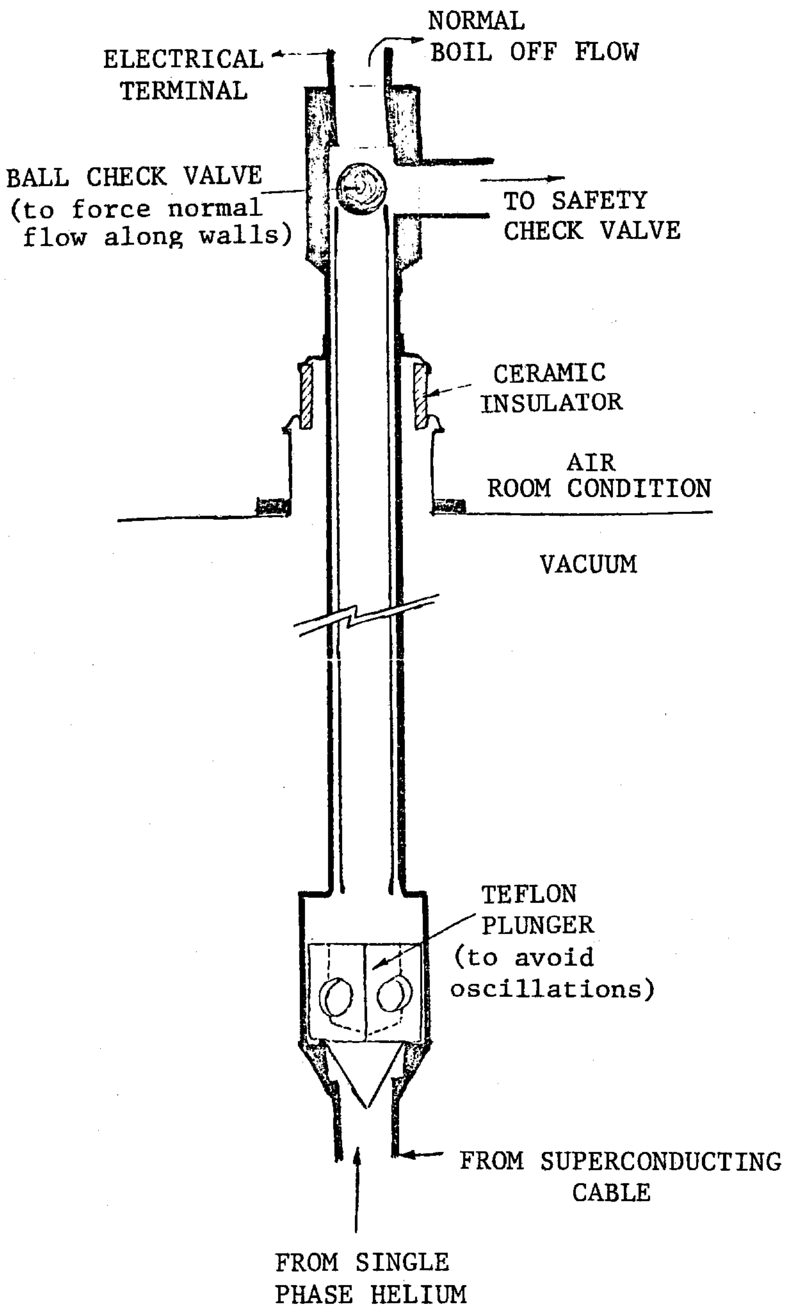

FIGURE 1 SAFETY LEAD

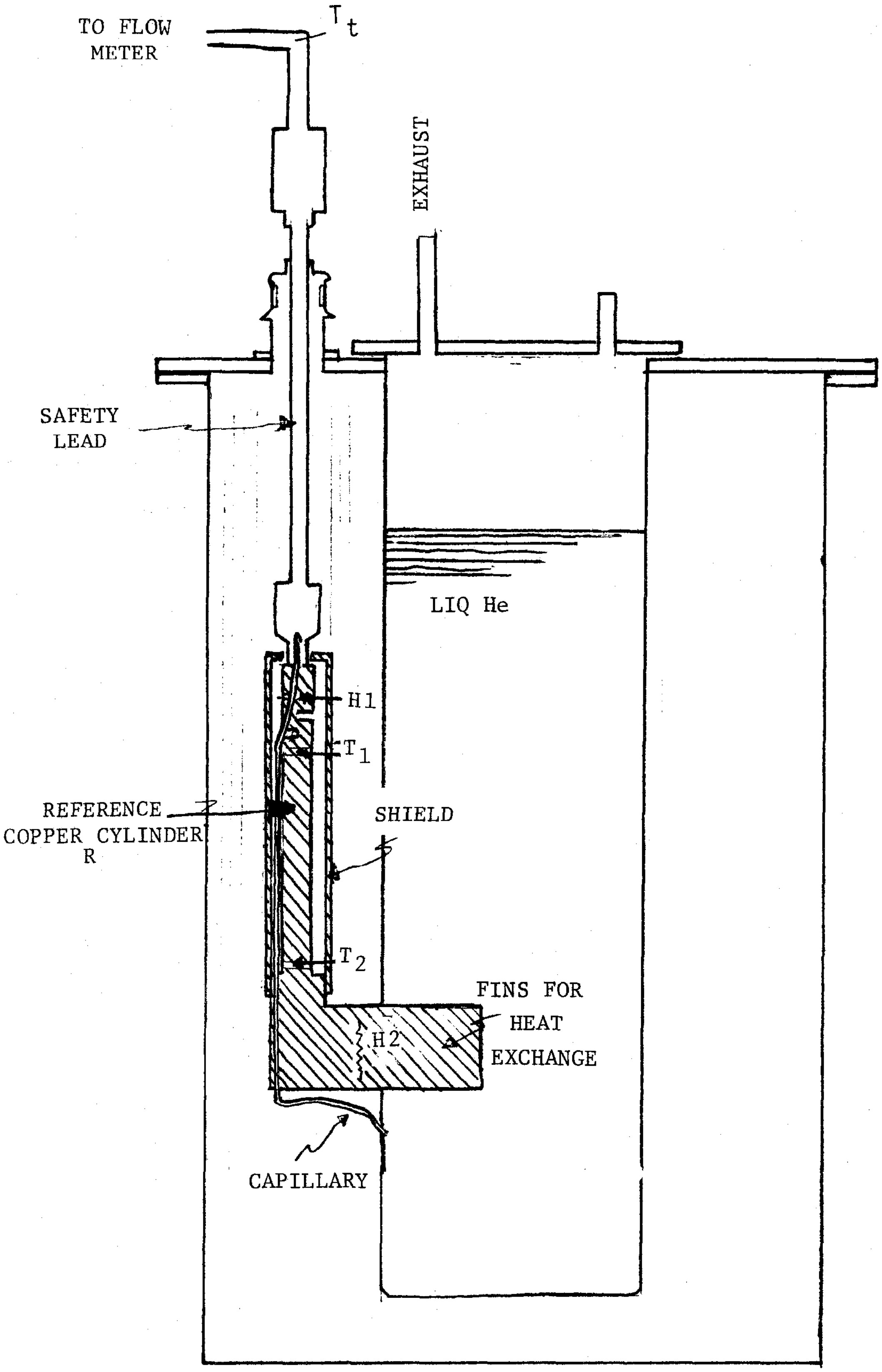

FIGURE 2 EXPERIMENTAL SETUP

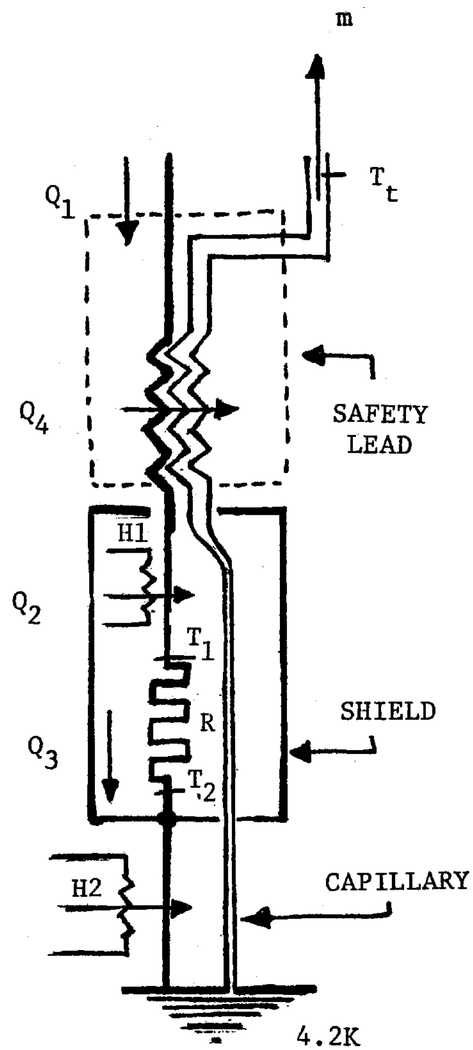

FIGURE 3 THERMAL CIRCUIT OF THE EXPERIMENTAL SETUP

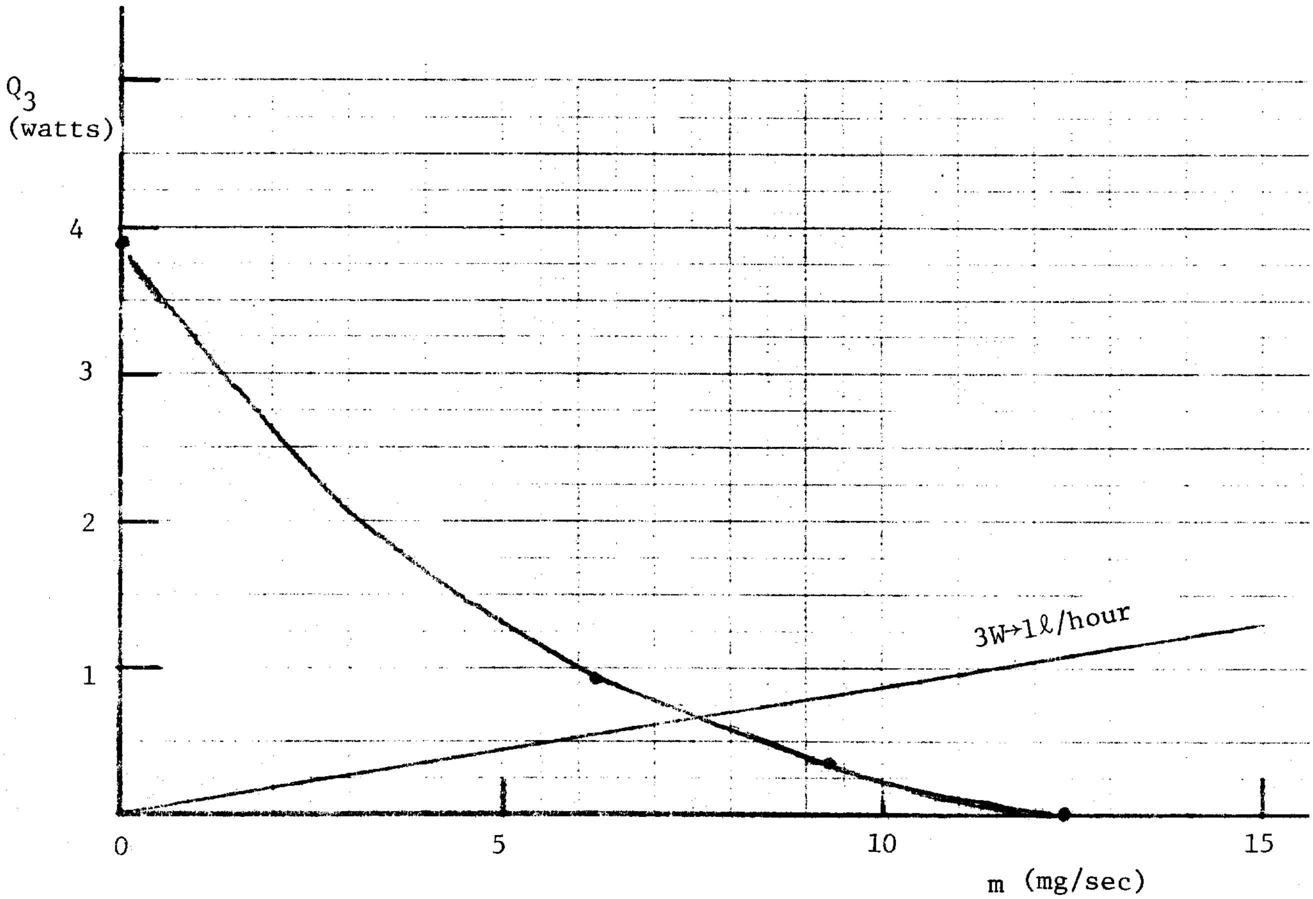

FIGURE 4 SAFETY LEAD HEAT LOAD AS FUNCTION OF GAS FLOW

TABLE I

R CALIBRATION DATA

DATE	T_1	T_2	H1	H2	T_1-T_2
761029	4.229 K	4.239 K	0W	0W	-.010 K
	4.443	4.298	.300	0	.145
	4.658	4.354	.595	0	.304
	4.866	4.422	.901	0	.444
	5.055	4.488	1.200	0	.567
	4.993	4.466	1.101	0	.527
	5.232	4.552	1.500	0	.680
	5.399	4.615	1.799	0	.784
	5.583	4.677	2.103	0	.906
	5.754	4.737	2.402	0	1.017
	5.918	4.798	2.700	0	1.120
	6.034	4.952	2.698	3.754	1.082
	5.277	4.690	1.349	3.752	.587
761101	4.250	4.260	0	0	-.010
	4.379	4.396	0	2.010	-.017
	4.497	4.518	0	3.990	-.021
	4.590	4.614	0	7.922	-.024
761105	7.481	5.389	6.009	0	2.092
	6.952	5.192	4.79	0	1.760
	6.384	4.971	3,598	0	1.413
	5.575	4.739	2.395	0	1.018
	5.069	4.493	1.215	0	.576
	4.228	4.237	0	0	-.009
	5.100	5.143	0	19.628	-.043
	5.007	5.045	0	16.99	-.038
	4.916	4.951	0	14.013	-.035
	4.783	4.813	0	10.989	-.030
	4.526	4.547	0	5.986	-.021
	4.222	4.232	0	0	-.010

TABLE II

DATA

DATA #	T_1	T_2	T_t	$\dot{m}$	Q_2	Q_3	Q_4	Q_1
27 A	6.705 K	5.193 K	-	0 mg/sec	0 W	3.92W	0 W	4.06 W
B	6.914	5.271	-	0	.300	4.38	0	4.19
C	7.064	5.354	-	0	.597	4.62	0	4.15
D	7.302	5.463	-	0	.917	5.08	0	4.31
E	7.387	5.482	-	0	1.216	5.32	0	4.24
31 A	4.449	4.512	194.1 K	12.42	0	.01	12.59	12.60
B	4.689	4.546	194.3	12.23	.298	.31	12.41	12.42
C	4.865	4.586	195.1	12.48	.584	.58	12.71	12.71
D	5.061	4.651	193.9	12.33	.9198	.86	12.48	12.42
E	5.236	4.718	193.3	12.52	1.225	1.13	12.64	12.55
32 A	4.692	4.528	210.5	9.30	0	.36	10.22	10.58
B	4.901	4.603	212.2	9.40	.298	.62	10.41	10.73
C	5.084	4.662	212.0	9.35	.599	.89	10.35	10.64
D	5.270	4.727	212.7	9.54	.924	1.20	10.59	10.87
E	5.451	4.797	212.1	9.41	1.24	1.48	10.42	10.66
33 A	5.102	4.666	231.7	6.24	0	.93	7.54	8.47
B	5.293	4.751	234.1	6.36	.3	1.19	7.77	8.66
C	5.446	4.804	233.8	6.35	.604	1.44	7.74	8.58
D	5.646	4.864	234.4	6.20	.898	1.85	7.58	8.53
E	5.839	4.930	235.0	6.15	1.295	2.20	7.54	8.45